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(54) APPARATUS FOR DETERMINING THE EFFICIENCY OF A HEATING APPLIANCE

(71) We, N.V. NEDERLANDSE GASUNIE, a Netherlands Limited Liability Company, of P.O. Box 19, Groningen, The Netherlands, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to apparatus for determining the efficiency of a heating appliance, which apparatus comprises measuring instruments for generating electrical signals responsive to the temperature, and to the oxygen content or the carbon dioxide content, of flue gases leaving the heating appliance.

The efficiency of heating appliances for example central heating installations, geysers and boilers may be measured according to the equation

$$\eta = \frac{\text{heat applied—heat of flue gases}}{\text{heat supplied}}$$

The heat supplied is the amount of calories theoretically produced by complete combustion of the fuel used. The degree of efficiency is affected by the design and operating conditions, particularly the fuel/air ratio. The percentage of heat loss (heat supplied—heat of flue gases), is approximately represented by Siegert's equation

$$w = f\frac{T-t}{[CO_2]}, \text{ in which}$$

w = percentage heat loss at complete combustion;

f = the so-called Siegert coefficient, which is dependent on the fuel;

T = the temperature of the flue gases °C;

t = the temperature of the combustion air supplied, °C;

$[CO_2]$ = the carbon dioxide content of the flue gases, % by vol.

Sieger's coefficient, f, is not quite constant for any given fuel, but is to some degree dependent on the carbon dioxide content of the flue gases, $[CO_2]$.

If not the carbon dioxide content but the oxygen content of the exit gases is measured, the percentage loss is approximately represented by a similar equation

$$w = f'\frac{T-t}{[O_2]_{atm} - [O_2]}, \text{ in which}$$

f' = a coefficient (different from f) dependent on the fuel;

$[O_2]$ = the oxygen content of the flue gases, % by vol.;

$[O_2]_{atm}$ = the oxygen content at atmospheric pressure of the combustion air supplied, % by vol.

In most instances the oxygen content of the combustion air is 21%.

It is found in practice that the heating appliance is not adjusted for optimum efficiency. One reason is that the separate measuring of the carbon dioxide or oxygen content and the temperature of the flue gases, and the calculation from these measurements of the efficiency by means of Siegert's equation, is too complicated and time-consuming for the average operator. Thus there is a requirement for apparatus which can indicate simply and rapidly the degree of operating efficiency and also for indicating the cause of the operating efficiency not being at a maximum.

It is the object of the invention to provide apparatus which will fulfil the above requirement.

The invention provides apparatus for determining the efficiency during operating of a heating appliance, which apparatus comprises measuring instruments for generating electrical signals responsive to the temperature, and to

the oxygen content or the carbon dioxide content of the flue gases leaving the heating appliance, characterized in that the said measuring instruments are connected to a computing device capable of digital presentation of the operating efficiency (η) after it has computed the said quantity η from the measuring data received in the form of the said electric signals, in accordance with the equation:

$$\eta = D - \left[\frac{A}{[O_2]_{atm} - [O_2]} + C\right] \Delta T$$

or

$$\eta = D - \left[\frac{B}{[CO_2]} + C\right] \Delta T,$$

in which

$[O_2]$ = the measured oxygen content of the flue gases, % by vol.;

$[O_2]_{atm}$ = the oxygen content at atmospheric pressure of the combustion air supplied, % by vol.;

$[CO_2]$ = the measured carbon dioxide content of the flue gases, % by vol.;

A, B, C, D = constants that are pre-set into the said computing device and whose values depend on the fuel used in the said heating appliance;

Δ_T = the difference between the temperature T of the flue gases and a reference temperature.

Usually the temperature of the combustion air supplied is taken as the reference temperature, and $[O_2]_{atm}$ is put equal to 21%.

For any given fuel the quantity D is determined by:

$$D = \frac{\text{lower calorific value}}{\text{upper calorific value}} \times 100\%$$

The apparatus according to the invention is particularly suitable for determining the efficiency of heating appliances using natural gas as fuel, e.g. containing 81.3% CH_4, 14.4% N_2 and 0.9% CO_2. The values of A, B and C for Groningen natural gas and for arbitrarily chosen types of domestic heating oil, fuel oil and coke are set forth in the accompanying Table.

	A	B	C
Groningen natural gas	0.78	0.34	0.0076
Domestic heating oil	0.67	0.48	0.0075
Fuel oil	0.67	0.51	0.0062
Coke	0.84	0.69	0.0043

For other types of gas, oil or coke different values may apply. The constants A, B, C and D usually have the following values:

A: between 0.6 and 0.9
B: between 0.3 and 0.8
C: between 0.004 and 0.009
D: between 75 and 95.

Apparatus according to the invention for use in efficiency measurements on heating appliances firing different types of fuel is preferably provided with means for setting the constants A or B, C and D to the values for the particular fuel used.

For natural or synthetic gas as fuel, the constants A or B, C and D are preferably adjusted or adjustable to values not differing from the following values by more than 10%:

A = 0.78
B = 0.34
C = 0.0076
D = 90.

So as to provide an indication of the cause of a possible failure of a heating appliance to reach the optimum efficiency, apparatus according to the invention is preferably provided with means by which also the measured temperature T, can be presented in digital form and/or means by which also the air excess (n), the air factor (as hereinafter defined), the measured oxygen content, $[O_2]$, and/or the measured carbon dioxide content, $[CO_2]$, can be presented in digital form. It is preferred that the apparatus is of such design that the computing device can present the 'air excess' (n) in digital form as a per-

centage, after having computed this quantity from the measuring datum in the form of the abovementioned electric signals in accordance with the equation:

$$n = \frac{[O_2]}{[O_2]_{atm}} \times 100\%$$

or:

$$n = \frac{[CO_2]_{max} - [CO_2]}{[CO_2]_{max}} \times 100\%,$$

in which:

n = the air excess, %;

$[CO_2]_{max}$ = the maximum possible value of the carbon dioxide content of the flue gases, % by vol, for the fuel used in the heating appliance, i.e. the value holding at stoichiometric quantity of the air supplied and for complete combustion; and

$[O_2]$, $[O_2]_{atm}$, $[CO_2]$ have the same meanings as explained before.

It is also possible to have the apparatus present the air factor (L), as a ratio in digital form. The term 'air factor' is hereby defined as a quantity L satisfying the following equation:

$$L = \frac{Q}{Q_{(min)}}, \text{ in which}$$

Q = the quantity of air supplied;

$Q_{(min)}$ = the minimum quantity of combustion air required for stoichiometroic combustion.

Also the 'air factor' can be calculated from the measured oxygen or carbon dioxide content; however, preference is given to the use of the 'air excess' as defined above.

If the apparatus according to the invention is of such design that the computing device can determine the air excess n from $[CO_2]$, as indicated above, the apparatus is preferably provided with means for setting the quantity $[CO_2]_{max}$ to a value in accordance with the fuel fired by the heating appliance. For Groningen natural gas $[CO_2]_{max}$ = 11.8%.

The invention is hereinafter particularly described and illustrated in the accompanying drawing, which is a schematic representation of one embodiment of a device according to the invention.

The features in the drawing have the following references:

1. A heating appliance firing natural gas;
2. A flue for the removal of flue gases from the heating appliance 1;
3. An exhaust pyrometer by means of which hot flue gases can be drawn from the flue 2 at about the place where this joins the heating appliance 1;
4. The suction tube of the exhaust pyrometer 3;
5. A thermocouple by means of which the temperature of the hot flue gases drawn off by the exhaust pyrometer can be measured;
6. A fan by means of which flue gases can be drawn off through the suction tube;
7. A cooler for cooling the gas drawn off;
8. A fan by means of which cooling air can be drawn through the cooler 7;
9. A gas line (pipe or flexible tube) connecting to the fan 6, for further conducting the cooled combustion gas to:
10. An analyzer which receives cooled combustion gases through the line 9 and can generate an electric signal commensurate with the carbon dioxide content of the combustion gases;
11. A measuring circuit connected to the thermocouple 5 and capable of generating an electric signal commensurate with the measured temperature, T, of the hot combustion gases;
12. An electronic computing device which receives the output signals of the analyzer 10 and the temperature measuring circuit 11, and is capable of computing therefrom the efficiency η and the air excess n, as hereinbefore referred to;
13. A selector switch by means of which the applicable values of the required constants can be simultaneously set in the computing device 12 for a given type of fuel. This switch is shown as a rotary switch, but may be of a different type e.g. a switch with selector buttons;
14. A digital display unit connected to the computing device 12, presenting in digital form the air excess (n), the temperature of the combustion gases (T_r), and the efficiency η;
15. A casing, accommodating parts 10 to 14.

WHAT WE CLAIM IS:—

1. Apparatus for determining the efficiency during operation of a heating appliance, which apparatus comprises measuring instruments for generating electrical signals responsive to the temperature and to the oxygen content or carbon dioxide content of the flue gases leaving the heating appliance, characterized in that the said measuring instruments are connected to a computing device capable of digital presentation of the operating efficiency (η) after having computed the said quantity η from the data received in the form of the said electric signals, in accordance with the equation:

$$\eta = D - \left[\frac{A}{[O_2]_{atm} - [O_2]} + C\right] \Delta T$$

or

$$\eta = D - \left[\frac{B}{[CO_2]} + C \right] \Delta T,$$

in which

$[O_2]$ = the measured oxygen content of the flue gases, % by vol.;

$[O_2]_{atm}$ = the oxygen content of the combustion air supplied, % by vol.;

$[CO_2]$ = the measured carbon dioxide content of the flue gases, % by vol.;

A, B, C, D = constants that are pre-set into the said computing device and whose values depend on the fuel used in the said heating appliance;

ΔT = the difference between the temperature T of the flue gases and a reference temperature.

2. Apparatus according to Claim 1, provided with setting means for setting the quantities A or B, C and D in the said computing device for values for fuel to be used in the said heating appliance.

3. Apparatus according to Claim 1 or Claim 2, wherein the quantities A or B and C and D are adjusted or adjustable between the values:

A: between 0.6 and 0.9;
B: between 0.3 and 0.8;
C: between 0.004 and 0.009;
D: between 75 and 95.

4. Apparatus according to Claim 3, wherein the said quantities A or B, C and D are adjusted or adjustable to values not differing from the following values by more than 10%:

A = 0.78;
B = 0.34;
C = 0.0076;
D = 90.

5. Apparatus according to any of Claims 1 to 4, wherein the measured flue gas temperature, T, is presentable in digital form.

6. Apparatus according to any of Claims 1 to 5, wherein the air excess, the air factor (as hereinbefore defined), the measured oxygen content, $[O_2)$, or the measured carbon dioxide content, $[CO_2]$, is presentable in digital form.

7. Apparatus according to Claim 6, wherein the computing device can present a quantity n in digital form after having computed the said quantity n from the measuring data received in the form of the said electric signals, in accordance with the equation:

$$n = \frac{[O_2]}{[O_2]_{atm}} \times 100\%$$

or

$$n = \frac{[CO_2]_{max} - [CO_2]}{[CO_2]_{max}} \times 100\%$$

in which:

n = the air excess, %;

$[CO_2]_{max}$ = the maximum possible value of the carbon dioxide content of the flue gases, % by vol., for a particular fuel used in the heating appliance; and

$[O_2]$, $[O_2]_{atm}$, $[CO_2]$ have the meanings set forth in Claim 1.

8. Apparatus according to Claim 7, provided with means for measuring the carbon dioxide content $[CO_2]$ of the flue gases, and with means for setting the quantity $[CO_2]_{max}$ to a value in accordance with the fuel to be used by the said heating appliance.

9. Apparatus according to any of Claims 1 to 8, wherein a selector switch is provided by means of which the values of the required constants A, B, C, D and $[CO_2]_{max}$ can be simultaneously set in the computing device for a given type of fuel.

10. Apparatus according to any one of Claims 1 to 9, provided with an exhaust pyrometer for determining the temperature T of the flue gases.

11. Apparatus according to Claim 10, wherein the said exhaust pyrometer also serves for aspirating sample gas for the determination of $[O_2]$ or $[CO_2]$.

12. Apparatus according to Claim 1, substantially as hereinbefore described with particular reference to the drawing.

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1562536 COMPLETE SPECIFICATION

1 SHEET *This drawing is a reproduction of the Original on a reduced scale*